

Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

seul
3.9
322

RESPONSE OF TREE SEEDLINGS TO EXTENDED PHOTOPERIODS

+

²
R.A. [Read,
W.T. [Bagley]

U. S. DEPT. OF AGRICULTURE
NATIONAL AGRICULTURAL LIBRARY
NOV 17 1967
CURRENT SERIAL RECORDS



RESPONSE OF TREE SEEDLINGS TO EXTENDED PHOTOPERIODS

by

R
Ralph A. Read, Principal Silviculturist

Rocky Mountain Forest and Range Experiment Station¹

and

Walter T. Bagley, Associate Professor of Horticulture and Forestry

Nebraska Agricultural Experiment Station²

¹ Central headquarters maintained in cooperation with Colorado State University at Fort Collins; author is located at Lincoln in cooperation with the University of Nebraska.

² College of Agriculture, University of Nebraska, Lincoln.

CONTENTS

	Page
Procedure	1
Experiment A	3
Experiment B	3
Experiment C	4
Experiment D	4
Experiment E	4
Experiment F	4
Experiment G	4
Results	5
Ponderosa pine	5
Austrian pine	9
Eastern redcedar	11
Oaks	13
Cottonwood	14
Summary and conclusions	15
Literature cited	16

Response Of Tree Seedlings To Extended Photoperiods

by

Ralph A. Read and Walter T. Bagley

Nursery production of conifers of sufficient size and quality for field planting in the Central and Northern Great Plains usually requires 2 to 3 years for eastern redcedar and 3 to 4 years for ponderosa and Austrian pines. If a practical way could be found to stimulate growth, seedlings of required size and quality for planting might be grown in less time. Nursery space requirements and costs of planting stock might be reduced.

Lengthening the photoperiod by supplemental lighting has stimulated growth of some tree species. Jester and Kramer (1939)³ state that use of lights to increase the amount of seedling growth of certain species in the nursery may be practical under some circumstances. Watt (1961) stated that an extended 20-hour photoperiod of white light during second-year growth of selected origins of white and black spruce seedlings significantly increased top growth, and reduced percentage of small (cull) seedlings, an important factor in nursery stock production.

Studies of vegetative responses of woody plants to extended photoperiods have been reviewed by Wareing (1956), Downs and Piringer (1958), and Watt and McGregor (1963). No research with supplemental lighting has been done previously in Great Plains tree nurseries; moreover, few studies have used light interruptions of the dark period in extending photoperiods of tree species used in this region.

The purpose of experiments described here was to determine response to supplemental

white light of some tree species commonly used for planting in the Great Plains. Two separate groups of experiments are described. In experiments A through E, individually potted seedlings were subjected to extended photoperiods in the greenhouse during winter, and then moved outside under the same treatments during the growing season.

After results of these potted seedling tests were evaluated and found to be encouraging, two other experiments, F and G, were made in seedling plots and beds of a large nursery operated by the U. S. Forest Service near Halsey, Nebraska.

Species studied in experiments A through E were: Eastern redcedar, Juniperus virginiana L.; ponderosa pine, Pinus ponderosa var. scopulorum Engelm.; Austrian pine, Pinus nigra Arnold; lanceleaf cottonwood, Populus × acuminata Rydb.; bur oak, Quercus macrocarpa Michx.; white oak, Quercus alba L.; and red oak, Quercus rubra L. Only ponderosa pine, Austrian pine, and eastern redcedar were studied in the nursery experiments.

Procedure

Four photoperiod treatments (fig. 1) were used in experiments A through E. The normal (N) treatment in the greenhouse was 14 hours' light; artificial lights were used to attain this treatment during winter. Outside, N treatment was the natural period of daylight throughout the growing season. In the N + 1 treatment, artificial light was added between 11:00 p.m. and 1:00 a.m.; in the N + 2 treatment it was added between 10:00 and 11:00 p.m. and 1:00 and 2:00 a.m. Lights were on during all dark hours for the 24-hour photoperiod.

³ Names and dates in parentheses refer to Literature Cited, p. 16.

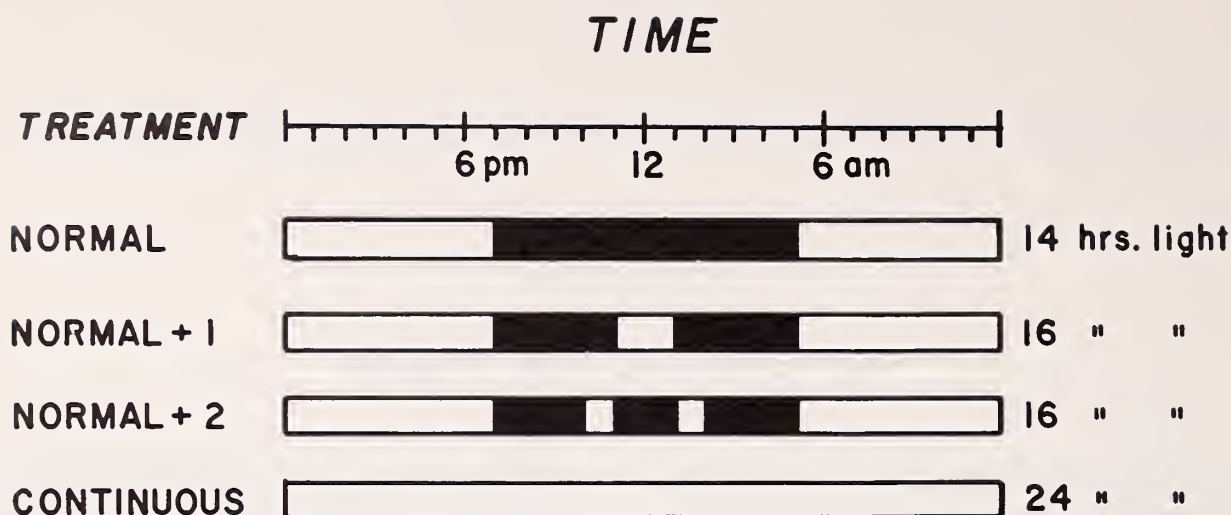


Figure 1.--The four photoperiod treatments tested.

Temperatures in the greenhouse ranged between 70° and 85° F. Daylight-type fluorescent tubes and 300-watt incandescent bulbs provided 150 to 200 foot-candles of supplemental light at plant height. The periods of cold storage between some treatment periods were in a 40° F. room lighted artificially 10 hours a day.

Experiments were set up outside during the growing season by placing the potted seedlings in gravel beds. The treatments were separated by tar-paper-covered barriers. Five 300-watt incandescent bulbs provided supplemental light of 120 to 160 foot-candles at plant height for each treatment.

Seedling heights were measured every 2 to 4 weeks. Total green weights and top and root volumes were measured at the end of treatment periods. A nondestructive method was used, since most seedlings were to be field planted after treatment. Root and total volumes were determined by water displacement. Top volumes were calculated by difference from total volume, and these data were used to calculate top-root ratios. Schedule of experiments A through E is given in table 1.

The later experiments conducted in the nursery were of two types: Experiment F consisted of four treatments on small separate plots sowed to several known source lots of ponderosa pine and Austrian pine seed. Experiment G consisted of three treatments in-

stalled on previously established production beds of seedling or transplant ponderosa pine and eastern redcedar.

Treatments were in effect from July 15 to October 4 the first season, and from April 1 to September 22 the second season. The normal daylight received by all plots when established July 15, was about 15 hours; this decreased to 12 hours by October 4. Plots were under treatment the entire second growing season, starting with 12 hours' normal daylight on March 21, increasing to 15 hours by June 21, and decreasing to 12 hours by October. Artificial lighting supplemented these normal daylight hours to provide the total hours of light for each treatment.

The sources of supplemental lighting (and concomitant heat) were clear 500-watt Mazda⁴ lamps in deep 20-inch aluminum reflectors, which were erected 5 feet above plot centers. Light-intensity readings at the soil surface directly beneath each source ranged from 350 to 450 foot-candles during the night. All plots and nursery beds received normal watering and weeding treatments of the production nursery. The soil of this nursery is a deep loamy sand, relatively low in nitrogen, and about neutral in reaction.

⁴ Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.

Table 1.--Schedule of experiments with potted seedlings, showing duration of treatments in italics

Time schedule	EXPERIMENT A	EXPERIMENT B	EXPERIMENT C	EXPERIMENT D	EXPERIMENT E
	Ponderosa pine Austrian pine Eastern redcedar	Ponderosa pine Austrian pine	Bur oak White oak Red oak	Eastern redcedar	Cottonwood
December	14 WEEKS GREENHOUSE & CHAMBERS				
January					
February					
March	-----				
April	Cold storage	Seeded			
May	-----	-----			
June					
July	24 WEEKS	24 WEEKS			
August	OUTSIDE	OUTSIDE			
September					
October	-----	-----			
November		Outside			
December	Out side	-----	Seeded		
January		24 WEEKS	-----		
February		GREENHOUSE			
March			15 WEEKS	Seeded	
April	-----		GREENHOUSE		
May	Field	-----	-----	-----	
June			Cold storage		
July		17 WEEKS	16 WEEKS	17 WEEKS	Seeded
August		OUTSIDE	OUTSIDE	OUTSIDE	
September		-----	-----	-----	
October			Cold storage	Cold storage	-----
November		Outside	-----		
December					20 WEEKS GREENHOUSE
January			16 WEEKS	29 WEEKS	
February			GREENHOUSE	GREENHOUSE	
March			-----		-----
April		-----	Cold storage		
May		Field	Field	-----	
June					
July				24 WEEKS	
August				OUTSIDE	
September					
October				-----	
November				Outside	
December					
January					
February					
March				-----	
April				Field	

Experiment A

Sixty-four 1-year-old seedlings each of ponderosa pine and eastern redcedar, graded for uniformity, were potted individually in loamy sand and randomly assigned to the four treatments. Austrian pine seeds were planted in pots and placed under the treatments to germinate. After two periods of treatment, seedlings were left outside through the winter. After final measurements in April, the bare-root seedlings were planted in the field at Lincoln.

Experiment B

Austrian pine and ponderosa pine seeds were germinated in pots in the greenhouse in early spring. Seven weeks later, 100 individually potted seedlings of each species were graded for uniformity, randomly assigned to the treatments, and placed outside with the experiment A seedlings. After three treatment periods, the potted seedlings were left outside throughout the winter. After final measurements in April, the bare-root seedlings were planted in the field at Lincoln.

Experiment C

Red, white, and bur oak seedlings were placed under the normal and continuous-light treatments in the greenhouse. Bur oak was also placed in the N+1 treatment. After three treatment periods, final measurements were obtained. A second group of bur oak seedlings germinated during the winter were placed outside in early spring, but were not placed under light treatments until late May.

Experiment D

Twenty-five individually potted 4-week-old seedlings of eastern redcedar were assigned at random to each of the four light treatments and placed outside. After three treatment periods, seedlings were left outside for the winter. After final measurements in April, bare-root seedlings were planted in the field at Lincoln.

Experiment E

Lanceleaf cottonwood seedlings from seed collected from two trees in Carter Canyon, Scottsbluff County, Nebraska, were placed under the light treatments in the greenhouse in October. They were 1 to 5 centimeters (cm.) tall at this time. One hundred four seedlings of each of the two lots were divided randomly into four groups of equal size for the treatments. The experiment was terminated at the end of 20 weeks.

Experiment F

Eight 4-foot by 4-foot plots in two blocks of four plots each were laid out about 30 feet apart in the nursery. The following treatments were set up:

- 24 hours' continuous (24-C)--
supplemental light 6 p.m. to 6 a.m.
- 20 hours' continuous (20-C)--
supplemental light 6 to 10 p.m. and
2 to 6 a.m.
- 20 hours' interrupted (20-I)--
supplemental light 10 p.m. to 2 a.m.
- Check--
no supplemental light.

Each plot was divided into quadrants: two ponderosa pine, one Austrian pine, and one eastern redcedar. Species were assigned to quadrants at random. The eastern redcedar failed to germinate because of late sowing, and was thereafter ignored.

Main light treatment plots of each species were split into subplots for the individual seed lots from five ponderosa and two Austrian pine seed trees. The nonstratified seed lots were sowed at 3-inch spacing in separate rows in each quadrant. The ponderosa pine seed came from a natural stand along the Niobrara River in Keya Paha County, Nebraska. Austrian pine origins were two planted trees (original source unknown) in Antelope Park, Lincoln, Nebraska.

Although plots were sprayed at intervals with Thiram to control damping-off, considerable mortality occurred in all plots. The quadrants containing pines were filled in during the first month by transplanting seedlings of the same lots, from an extra plot germinated at the same time. Lack of supplemental light on these seedling transplants during the first month was considered unimportant in the final 2-year results. Final pine seedling stands were half the density desired, providing 8 instead of 16 seedlings per square foot.

Pine seedling heights, from cotyledon node to tip of terminal bud, were measured at the end of both growing seasons. Seedlings were dug the following spring, and total fresh weight of each obtained.

Experiment G

Two lights at least 30 feet apart were installed above each of three previously established production nursery beds, containing:

1. Ponderosa pine seedlings, 3 months old (fig. 2).
2. Eastern redcedar seedlings, 3 months old.
3. Eastern redcedar transplants, 15 months old.

Two treatments of 24 and 20 hours' continuous light, the same as two of the treatments in experiment F, were set up on the

Figure 2.--Two supplemental lights over a ponderosa pine seedling bed in experiment G.



automatic timer clocks. Treatments were not replicated. The unlighted segments of the nursery beds between the lighted places were considered as buffers, and the end segments beyond the lights were considered as checks. Because deep reflectors were used for the lights, both areas received little, if any, supplemental light from the side.

Seedlings were systematically sampled and measured at the end of both growing seasons. Height was measured on one seedling nearest to each 0.5-foot interval along each of five seedling rows. The two outside rows of the beds were not sampled. Sampling extended from one light to the other, and from 8 to 30 feet beyond each light. This sample provided 10 measurements for each lineal foot of bed length. Not all measurements were used in the final analysis. Data were summarized instead by 12-foot segments under the different treatments. Each segment mean was derived from the 125 seedlings in the systematic sample within each 12-foot segment of the bed.

Beds were dug the following spring, and samples of seedlings and transplants were retained from the treated and check segments. Top, root, and total fresh weights were measured, and proportion of tops that appeared dead was recorded.

Results

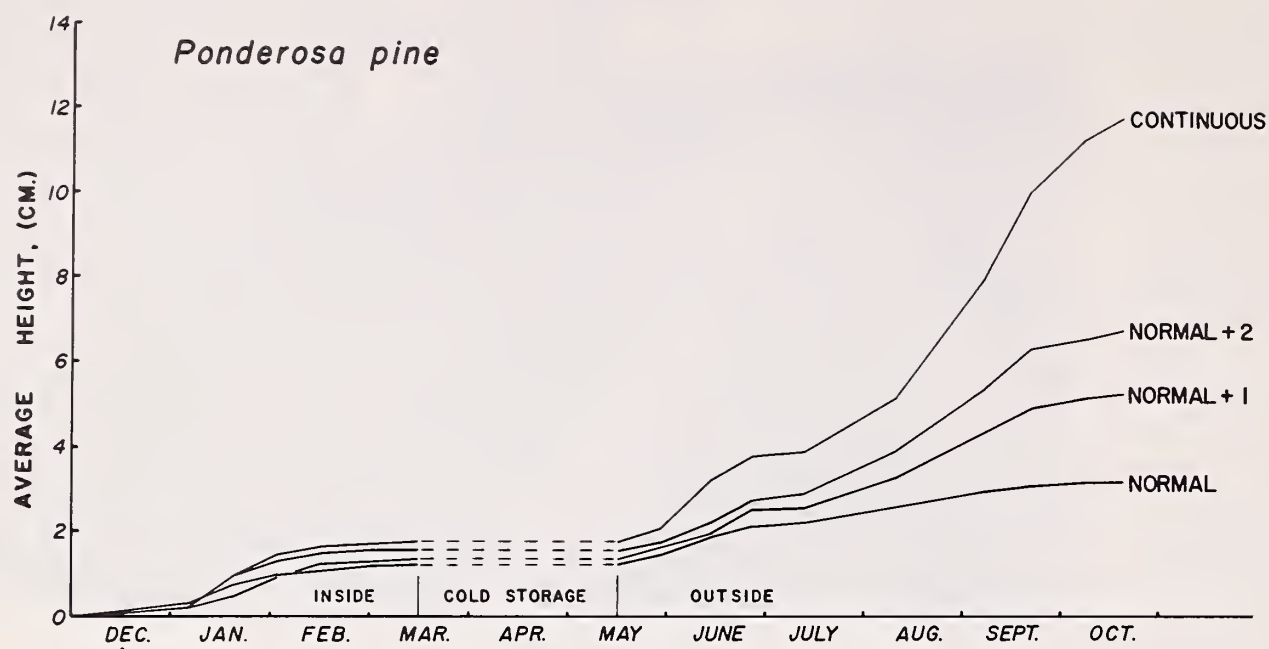
In considering the results of these studies, it should be kept in mind that the use of large

incandescent lamps probably raised air and surface soil temperatures around the plants. Since effects of supplemental light cannot be separated from those of temperature, results presented in this report should be interpreted as the combined effects of both. Under nursery conditions, temperature effects would normally accompany use of incandescent lamps, unless larger floodlights were installed at greater heights.

Specific responses are presented by tree species. Seedling heights, green weights, top and root volumes, top-root ratios, and other data are summarized in tables. Mean separations were calculated by Duncan's New Multiple Range Test, and where appropriate are indicated by underlines which connect means that do not differ significantly at the 5-percent probability level. Cumulative height curves show average growth response during the treatments.

Ponderosa Pine

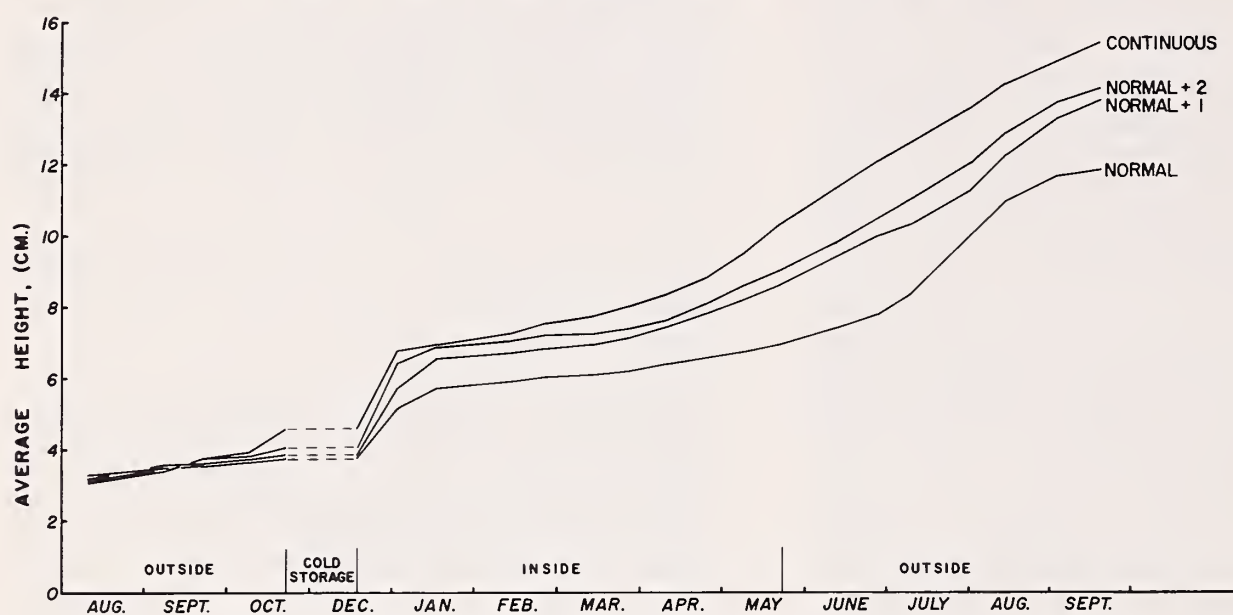
Differences among treatments were small during the first period in both experiments A and B (fig. 3). Seedlings under continuous light grew only slightly larger than those in all other treatments. At the end of the experiments, seedlings under continuous light were significantly taller, heavier, and had larger tops and roots than seedlings under the normal treatment (table 2; figs. 3, 4). In the N + 1 and N + 2 treatments, seedlings were intermediate in height response between the continuous and



EXPERIMENT A

Figure 3.--

Height growth
curves of
ponderosa pine.



EXPERIMENT B

Table 2. --Effect of treatments on characteristics of ponderosa pine in pots,
Experiments A and B

Characteristic	Experiment A, by treatment				Experiment B, by treatment			
	Normal	N + 1	N + 2	Continuous	Normal	N + 1	N + 2	Continuous
Seedlings (No.)	15	13	14	14	24	24	23	24
Initial height (cm.)	7.1	7.2	7.2	7.9	--	--	--	--
Total height (cm.)	10.3	12.5	14.0	19.7	12.0	14.0	14.2	15.5
Green weight (gm.)	24.8	23.4	32.9	43.1	37.6	40.8	37.2	53.8
Top volume (cc.)	11.9	13.6	17.7	24.4	17.9	21.6	20.1	28.4
Root volume (cc.)	12.9	9.8	15.2	18.7	18.6	18.1	16.8	23.4
Top-root (ratio)	1.0	1.4	1.2	1.4	1.0	1.3	1.3	1.2

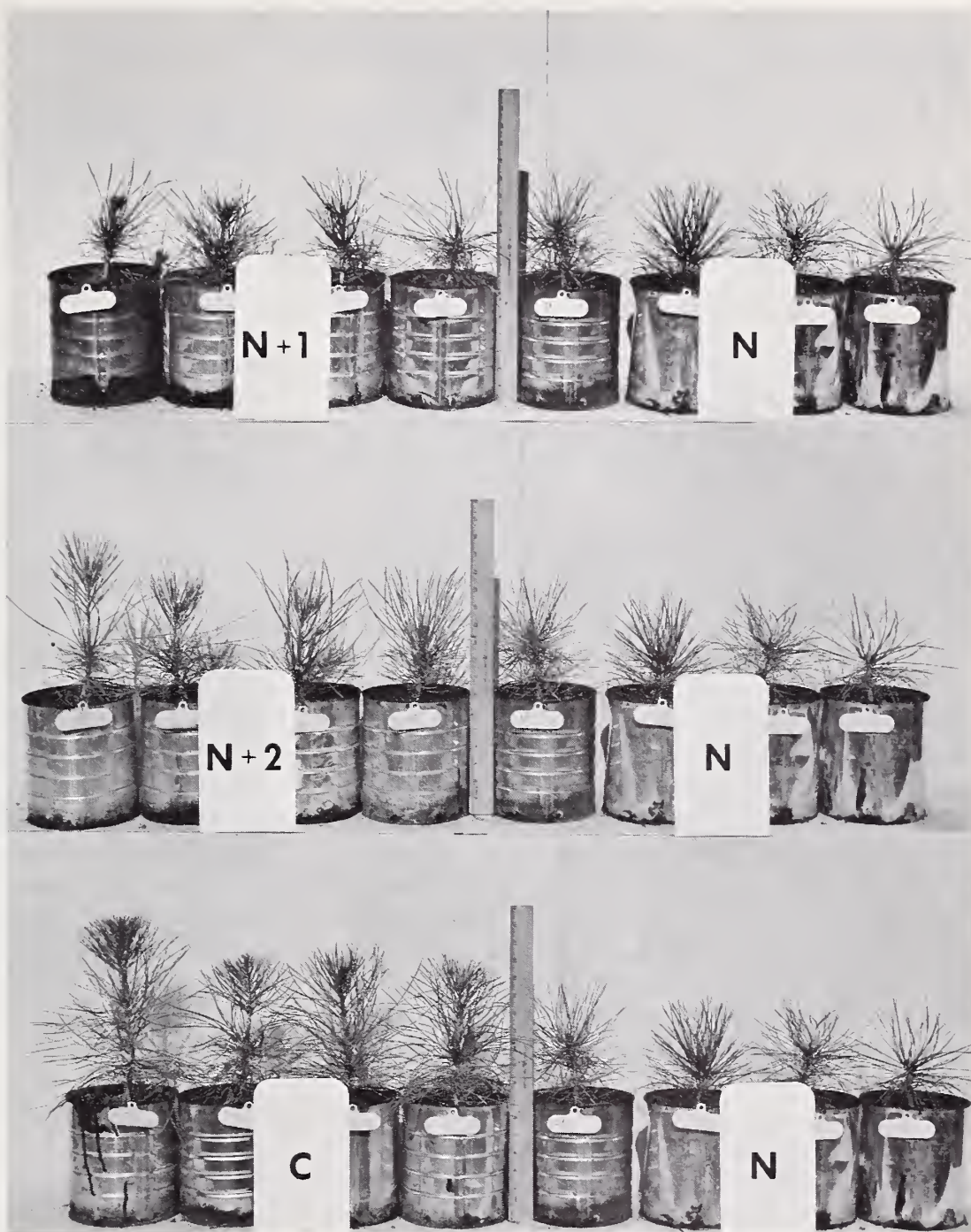


Figure 4.--Ponderosa pine seedlings at the end of treatment in experiment A. Scale is an 18-inch rule.

normal treatments. Seedlings under N + 2 were slightly taller than under N + 1.

Thirteen of 15 seedlings (85 percent) under continuous light in experiment A produced two or more growth flushes during the second period of treatment. In contrast, none of the seedlings under normal treatment flushed more than once. Seventy-one percent of the seedlings under N + 2 flushed more than once during the second period, while only 54 percent under N + 1 had two flushes. These findings agree with Wareing's (1956) that pine buds developed during summer dormancy will open prematurely and produce extension

growth under abnormally long photoperiods or continuous illumination. The first killing frost occurred 8 days after termination of treatment; thus seedlings had a rather short hardening-off period. Despite the presence of late growth flushing in the supplemental light treatments, no winter injury was evident on these seedlings.

Differences in height growth among treatments in the nursery plot, experiment F, were significant at the end of the second growing season (table 3). The two continuous supplemental light treatments of 20 and 24 hours produced the tallest seedlings, and the check

Table 3. --Effect of treatments on characteristics of 2 + 0 ponderosa pine in nursery plots,

Experiment F

Seed lot	Seedling height, by treatments					Seedling weight, by treatments				
	Check	20-I	20-C	Continuous	All	Check	20-I	20-C	Continuous	All
	----- Centimeters -----					----- Grams -----				
Lot 5	9.8	15.0	16.4	18.2	14.9	11.2	16.6	15.6	19.0	15.6
6	8.7	13.0	14.6	15.2	12.8	8.6	11.8	12.2	13.4	11.5
10	7.8	10.6	12.2	14.6	11.3	8.4	8.5	10.1	10.8	9.5
10a	7.9	11.6	15.1	13.0	11.9	6.4	9.0	13.6	10.0	9.8
8a	7.4	10.0	13.0	11.2	10.4	7.2	8.3	10.0	9.3	8.7
All lots	8.3	12.0	14.2	14.4	--	8.4	10.9	12.3	12.5	--

produced the shortest. The 20-hour interrupted treatment was intermediate in response, but not significantly larger than the check.

Variation in height growth of the different seed tree lots was also significant (table 3). Seedlings of lot 5 were taller under all treatments than seedlings of lot 8a. Lot 5 seedlings grew 86 percent faster, while lot 8a seedlings grew only 51 percent faster, under 24-hour continuous light as compared to the checks. In three of the five lots, the response was greatest under 24-hour continuous light; in the other two, maximum height growth was produced under the 20-hour continuous treatment. Treatment \times seedlot interaction was not significant, however.

As in the other experiments, height growth response to supplemental light in the nursery bed, experiment G, was very small during the first growing season (table 4). By the end of the second growing season, however, seedlings under both light treatments grew taller than those in the check area. Seedling growth under 20-hour continuous light was nearly twice that of the check. There was a slight difference in response between the 20- and 24-hour continuous treatments, which was not consistent with results in the plot experiment.

Seedling needles under continuous light in experiments A and B were significantly longer (8.3 cm.) than in other treatments (5.1 to 6.5 cm.). As a result, the amount of foliage was noticeably greater on all seedlings under continuous light.

Top and root volumes did not differ significantly among the N, N+1, and N+2 treatments in experiment B. The continuous treatment, however, produced significantly larger tops and roots. Top volumes equaled root volumes under normal treatment, but under all supplemental light treatments in both experiments A and B, the tops grew more than the roots (table 2). A favorable balance between tops and roots was maintained, however; top-root ratios in both experiments ranged between 1.0 and 1.4. First-year field survival ranged from 85 to 100 percent, and did not differ significantly among treatments.

Differences in fresh seedling weight in the nursery plot, experiment F, were not significant among treatments (table 3), but were significant among seed lots. Seedlings of lot 5 were heaviest, and those of lot 8a lightest. Seedling weights were arrayed in approximately the same order as seedling heights among treatments and seed lots, and interaction was not significant. Although there were minor differences in total weight and top-root

Table 4. --Effect of treatments on characteristics of 2 + 0 ponderosa pine in nursery beds, Experiment G

Characteristic	Treatment			
	Check	20-C	Buffer	Continuous
Height (cm.):				
First year	3.9	5.1	5.0	5.9
Second year	9.3	15.1	14.0	13.9
Growth	5.4	10.0	9.0	8.0
Weight (gm.)	--	5.0	6.0	4.5
Top-root (ratio)	--	3.8	3.9	3.7

ratio of seedlings by treatment in experiment G, none appeared significant (table 4).

No clear explanation can be offered for the "response" of seedlings in the buffer segment between the lights in experiment G (table 4). The buffer segment between the lights may have benefited somewhat by the heat from both lights. However, the average height of the 2 + 0 check seedlings (9.3 cm.) was similar to the 2 + 0 check seedlings (8.3 cm.) in experiment F. In addition, the 12-foot segments beneath each of the lights were the only portions of the entire bed that were different in foliage coloration. Seedling foliage under lights remained green instead of turning purplish at the end of the first growing season, as ponderosa pine of these origins normally does.

It appears the segments under lights at first may have been stimulated, then held back by an intense competition for nutrients. This particular nursery bed contained 107 seedlings per square foot at the end of the experiment--a stand density of 2.5 times that recommended for 2 + 0 ponderosa pine in this nursery. Seedling density was over 10 times that of the plots in experiment F. At the end of the second growing season, the seedlings under lighted segments were somewhat yellowish, as compared to the normal green of the unlighted segments.

Austrian Pine

Differences among treatments were small during the first period in both experiments A

and B, although seedlings under continuous light were noticeably larger than under other treatments (table 5; figs. 5, 6). Total response at the end of treatments differed in the two experiments.

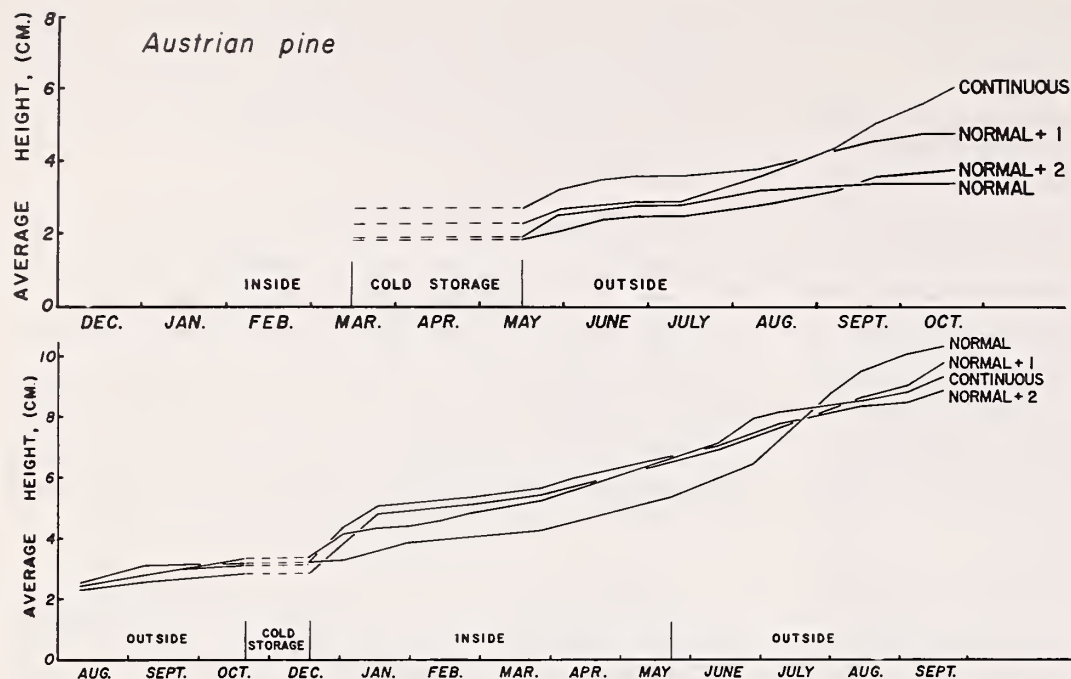
Seedlings under continuous light were significantly larger by all measures than those under other treatments in experiment A. In experiment B, however, there were no significant differences in height or weight among treatments. The seedlings under normal treatment, though smallest at the end of the first treatment periods, grew faster and surpassed all other treatments during the last period.

Height growth of the N + 1 treatment was intermediate to continuous and normal in experiment A; moreover, in both experiments the N + 1 response was greater than N + 2. Terminal extension was erratic under all supplemental light treatments, especially in experiment B. The lateral buds often flushed in a prolepsis-type growth. About half the seedlings under supplemental light treatments showed this inclination toward lateral growth, whereas in the normal treatment only 3 out of 23 trees showed this tendency.

A possible explanation for the differing results is that seedlings in experiment B were not subjected to a chilling break between the last two growth periods, whereas in experiment A, seedlings were held in cold storage for a few weeks between treatment periods. Seedlings under normal treatment in experiment B apparently went into winter dormancy after one growth flush. When placed outside under springtime growing conditions, these

Table 5. --Effect of treatments on characteristics of Austrian pine in pots,
Experiments A and B

Characteristic	Experiment A, by treatment				Experiment B, by treatment			
	Normal	N + 2	N + 1	Continuous	Normal	N + 2	N + 1	Continuous
Seedlings (No.)	15	16	16	16	23	23	24	25
Total height (cm.)	3.4	3.7	4.8	6.1	10.4	9.1	9.8	9.2
Green weight (gm.)	14.2	12.6	17.4	22.6	41.0	45.3	47.2	41.8
Top volume (cc.)	5.4	6.6	8.6	12.1	20.2	25.2	23.3	24.9
Root volume (cc.)	8.7	6.3	8.1	11.4	20.7	20.2	22.6	17.9
Top-root (ratio)	.6	1.1	1.1	1.1	1.0	1.3	1.1	1.5



EXPERIMENT A

Figure 5.--

Height growth
curves of
Austrian pine.

EXPERIMENT B

seedlings were physiologically ready to grow. In contrast, those under supplemental light first produced buds of the summer dormancy type, and then made two or more growth flushes. They were just going into a dormant period when they were moved outside. Austrian pine may have more specific chilling requirements than ponderosa for developing winter dormancy.

An interesting modification of growth on Austrian pines was the production of three-needle fascicles. Austrian pines normally grow only two-needle fascicles. The supplemental light treatments promoted this response in 20 of 25 seedlings under continuous light, 14 of 23 in the N + 2, and 10 of 24 in the N + 1. Only 1 of 23 seedlings under normal treatment had three-needle fascicles. Rudolph

(1964, pg. 15) mentions two studies in which increased numbers of needles per fascicle were found on lammas and prolepsis shoots of jack pine and red pine. According to Wareing (1956) extended daylength on short-day ecotypes of some species tends to produce lammas and/or prolepsis extension shoots.

Seedlings that produced late flushes of lammas or prolepsis shoots under continuous light suffered winter injury on the new growth; late growth flushes on ponderosa pine did not show this injury.

First-year field survival was high--from 81 to 100 percent--except for experiment B seedlings that had been under continuous light. Unfortunately, two-thirds of these were accidentally destroyed during cultivation. Less than

Figure 6.--Austrian pine seedlings after first treatment period. Grid scale is 10 centimeters.

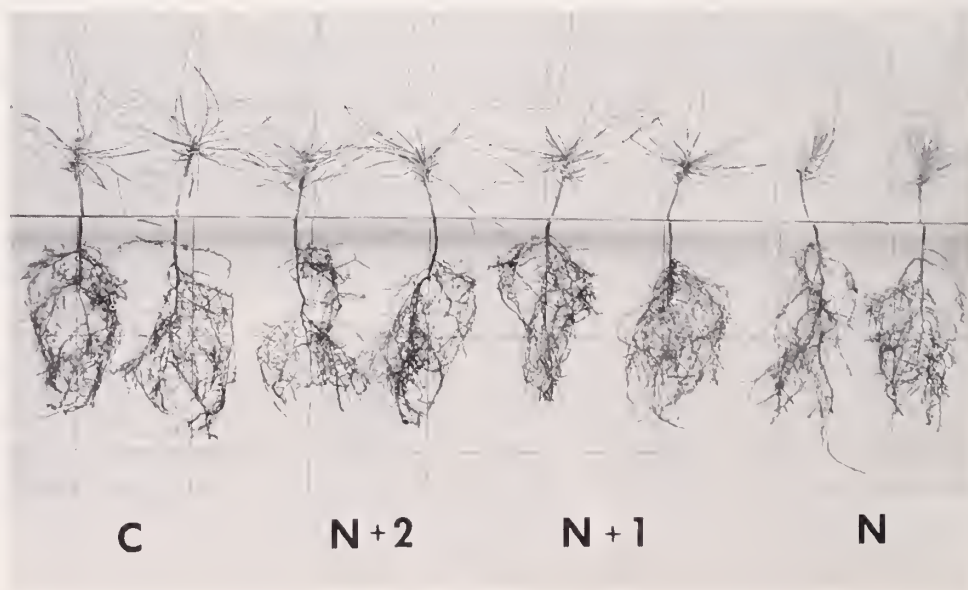


Table 6. --Effect of treatments on characteristics of 2 + 0 Austrian pine in nursery plots,

Experiment F

Seed lot	Seedling height, by treatment					Seedling weight, by treatment				
	Check	20-I	20-C	Continuous	All	Check	20-I	20-C	Continuous	All
	----- Centimeters -----					----- Grams -----				
Lot 2	7.8	9.0	8.6	7.6	8.2	11.7	10.9	10.1	8.8	10.5
3	5.6	7.8	8.9	6.8	7.2	9.2	9.2	8.2	5.9	8.6
All lots	6.7	8.4	8.7	7.2	--	10.4	10.0	9.2	7.3	--

50 percent of the remaining seedlings survived, which indicates winter injury to this treatment was significant.

In the nursery plot experiment there were no significant differences in seedling height or weight attributable to treatments (table 6). There appeared to be a tendency, however, for seedlings under the 20-hour continuous and 20-hour interrupted treatments to be taller than either the 24-hour continuous or check. Moreover, seedlings of the check and 20-hour interrupted treatments weighed more than those under 24-hour continuous light.

These responses are mentioned because they tend to be similar to those expressed by the potted Austrian pine in experiment B. As previously mentioned, Austrian pine in that experiment ultimately grew faster under 14 to 16 hours' light than under continuous light. It appears that apical dominance in some genotypes of Austrian pine is inhibited rather than stimulated by 24 hours of continuous light. On the other hand, some extension of the natural photoperiod evidently stimulates seedling height growth, but not total weight.

There was a tendency for seedlings of lot 2 to be taller and heavier than those of lot 3. This result, as in ponderosa pine, indicates the strong influence of genetic variability in response of seed lots from different trees.

Eastern Redcedar

In both experiments A and D, seedlings under continuous light grew significantly taller, heavier, and had larger tops and roots than those under normal treatment (table 7; figs. 7, 8). In both experiments, the N + 1 and N + 2 treatments were intermediate in response. The exception was in experiment D, where N + 2 seedlings were nearly as tall as under continuous light.

It should be noted that extension growth of *Juniperus*, unlike that of *Pinus*, is indeterminate. Growth extension and leaf development are not dependent on bud formation and breaking of dormancy, since no prominent buds are formed. Thus, in contrast to pines, the redcedars under all treatments showed a rapid response in height growth during the

Table 7. --Effect of treatments on characteristics of eastern redcedar in pots,

Experiments A and D

Characteristic	Experiment A, by treatment				Experiment D, by treatment			
	Normal	N + 1	N + 2	Continuous	Normal	N + 1	N + 2	Continuous
Seedlings (No.)	16	17	16	17	23	25	24	20
Initial height (cm.)	11.6	11.9	11.6	12.4	--	--	--	--
Total height (cm.)	26.3	31.7	32.3	35.5	29.1	37.0	41.1	43.3
Green weight (gm.)	60.6	59.7	68.4	96.0	48.9	56.8	59.2	82.7
Top volume (cc.)	24.9	29.0	32.3	48.7	24.7	32.4	34.1	51.1
Root volume (cc.)	35.8	30.7	36.1	47.4	24.2	24.4	25.1	31.4
Top-root (ratio)	.7	.9	.9	1.1	1.0	1.3	1.4	1.6
Winter damaged (pct.)	--	--	--	--	9	60	50	95

first period of treatment. Height growth was essentially linear in the greenhouse environment where temperatures were favorable and constant. Outside, however, growth curves became sigmoid (fig. 7). Experiment A seedlings responded rapidly when placed outside, whereas those in experiment D responded slowly. Daily temperatures during May and June for experiment A averaged 3° to 8°F. higher than in May and June of a different

year for experiment D. Growth increased rapidly during July and August, and tapered off again under cooler fall temperatures. In this later response redcedar was unlike the pines, which continued to grow under cool fall temperatures with additional light. Bagley and Read (1960) found that 45° F. night temperatures limited the growth of *Juniperus virginiana*, even under long photoperiod. Minimum temperatures in the 40's are common during September and October at Lincoln.

Ratio of tops to roots was affected by treatment in experiment D. Seedlings under normal day length developed a 1 to 1 top-root ratio, but those under continuous light had significantly more top than roots. The other two treatments were intermediate in response. Root growth during the second season may have been restricted by the potting containers.

Winter injury after treatment in experiment D was greater among seedlings under the supplemental light treatments than under the normal treatments (table 7). All experiment D stock failed in the field, which indicates it was in poor condition regardless of treatment. We think these seedlings suffered from lack of moisture in the pots over winter. All experiment A seedlings of all treatments survived field planting.

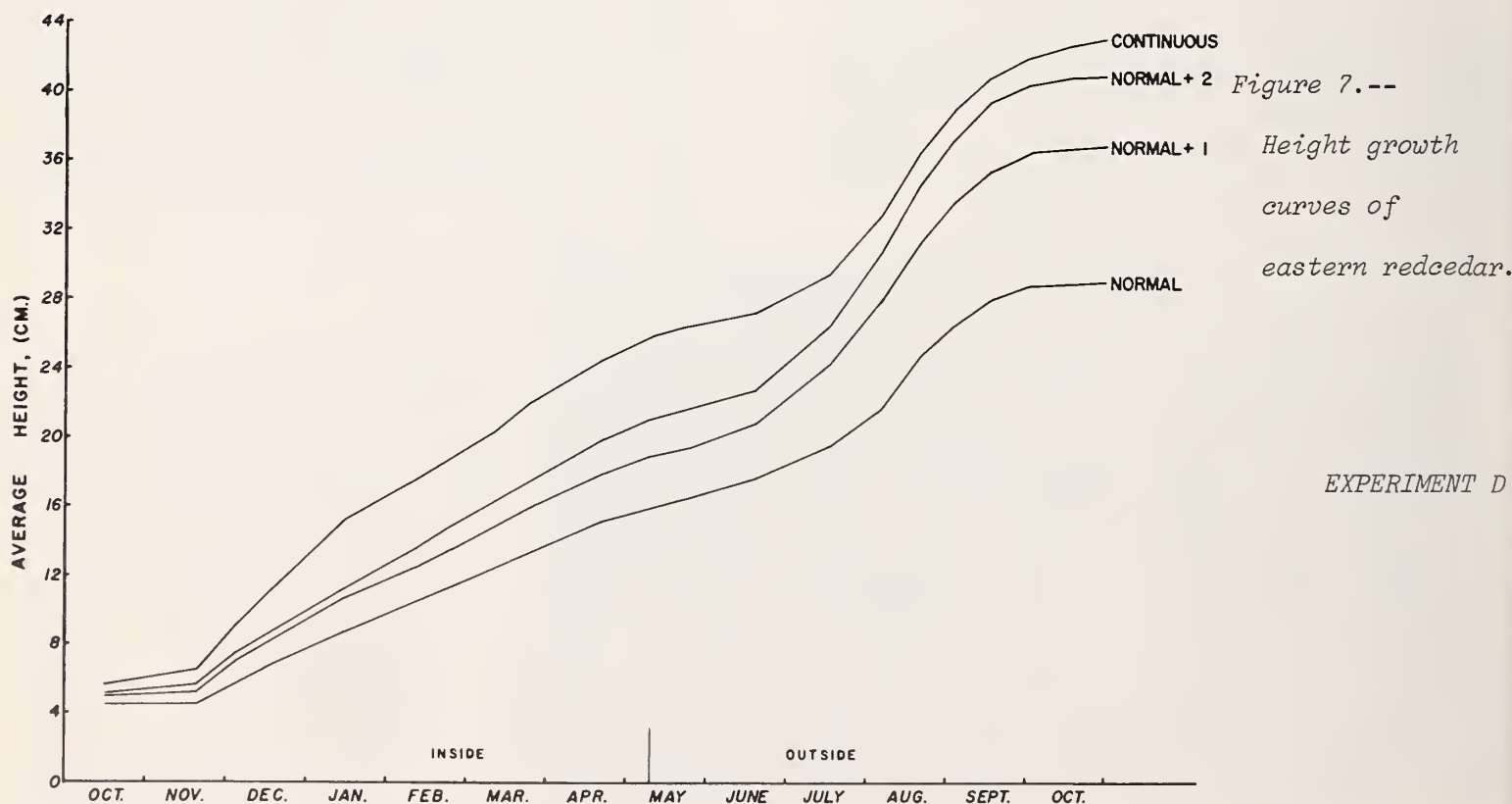
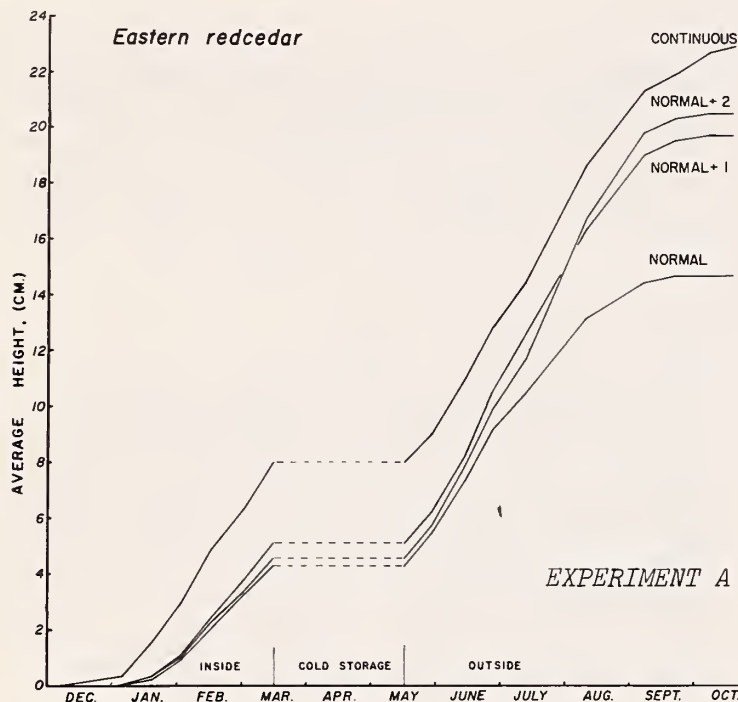


Figure 8.--Eastern redcedar seedlings at end of treatment in experiment A. Scale is an 18-inch rule.



In experiments conducted in the nursery, there was essentially no response to supplemental light during the first growing season in either seedlings or transplants. Height growth during the second growing season, however, was stimulated by 24-hour continuous light (table 8).

Seedlings under 24-hour continuous light averaged 6.2 cm. (2.5 inches) more growth than the check. The 20-hour treatment was intermediate in response, but almost as good as the 24-hour treatment. As with ponderosa pine seedlings, the buffer segment appeared to show some response.

General response of redcedar seedlings was strikingly greater than ponderosa pine seedlings in the nursery bed. Seedling density was only 21 per square foot, as contrasted to the overly dense ponderosa pine beds. Fresh weight of seedlings was greatest and top-root ratio most favorable under the 24-hour continuous light. On the other hand, the upper half of seedling tops under supplemental light were damaged during winter after the second growing season. Extent of this damage coincided with fall foliage color differences, in which seedlings under lights remained green, while those in check segments turned the usual reddish brown. The damaged seedlings were not killed, however, since lower portions of the tops resumed growth the following spring.

Transplants grew tallest under 24-hour continuous light, with 20 hours giving an intermediate response (table 8). The buffer segment showed less growth than the check, however. Both light treatments produced significantly heavier transplants than the buffer. Top-root ratios of all treatments were favorable. Transplant bed density averaged only 14 per square foot.

Foliage color differences in the fall were the same as noted for the redcedar seedlings. The transplants growing within the 12-foot segment beneath each of the lights remained green, while the remainder of the bed turned reddish brown. As a result of this stimulation effect, the trees under lights evidently were not dormant when the first killing frost occurred, and consequently the upper 28 percent of their crowns was killed. This apparently did not impair the survival ability of transplants, however, for the lower undamaged portion of the crowns remained vigorous. Partial killing back of tops was probably no different than top pruning by machine, and may actually have improved chances of survival by producing a more favorable top-root ratio.

Oaks

Bur oak seedlings grew taller under continuous light than under normal light over a

Table 8.--Effect of treatments on characteristics of eastern redcedar seedlings and transplants in nursery beds, Experiment G

Characteristic	Seedlings, by treatment				Transplants, by treatment			
	Check	20-C	Buffer	Continuous	Check	20-C	Buffer	Continuous
Height (cm.):								
First year	5.5	6.0	6.0	5.9	17.4	18.6	15.7	17.6
Second year	27.3	32.1	29.5	33.9	28.3	30.1	24.4	33.2
Growth	21.8	26.1	23.5	28.0	10.9	11.5	8.7	15.6
Weight (gm.)	--	11.1	10.4	14.1	--	35.1	18.3	32.6
Top-root (ratio)	--	4.0	3.7	3.0	--	1.7	1.5	2.8
Top damage (pct.)	0	43	2	56	0	28	0	28

Table 9. --Effect of treatments on characteristics of three oak species in pots,
Experiment C

Characteristic	Bur oak, by treatment			White oak, by treatment			Red oak, by treatment		
	Normal	N + 1	Continuous	Normal	N + 1	Continuous	Normal	N + 1	Continuous
Seedlings (No.)	16	16	16	9	--	9	10	--	10
Initial height (cm.)	7.4	6.3	7.1	6.8	--	7.4	8.3	--	7.2
Total height (cm.)	16.0	17.7	22.5	12.1	--	20.5	16.5	--	20.3
Green weight (gm.)	33.0	25.1	27.2	16.4	--	24.8	24.7	--	19.5

46-week period (table 9; fig. 9). The height response under the N+1 treatment was slightly greater than normal. Seedlings grown under normal light were heavier, however, and had larger root systems than those in the other treatments.

A second group of bur oak seedlings placed outside under the four light treatments during the summer for 17 weeks did not show a significant height response to additional light. More of these seedlings under N+1 and continuous treatments made a second flush of growth, however, and they produced more laterals than under the normal treatment.

The white oaks and red oaks grew tallest under continuous light. Although heaviest white oak seedlings were produced under continuous light, the heaviest red oaks, with largest root systems, were produced under the normal treatment (table 9).

The continuous treatment consistently produced a greater number of growth flushes in all three oak species. This agrees with results of other workers who have found that growth of oaks is not continuous, but occurs in a series of flushes under long photoperiods or continuous illumination (Wareing 1956). Height increased most during the first and third periods in the greenhouse. Failure to respond to light treatments outside during the second period indicates other dormancy factors were involved.

Cottonwood

All three supplemental light treatments produced seedlings that were significantly taller than those under normal treatment. There were no significant differences in height, however, among the three light treatments (table 10; fig. 10).

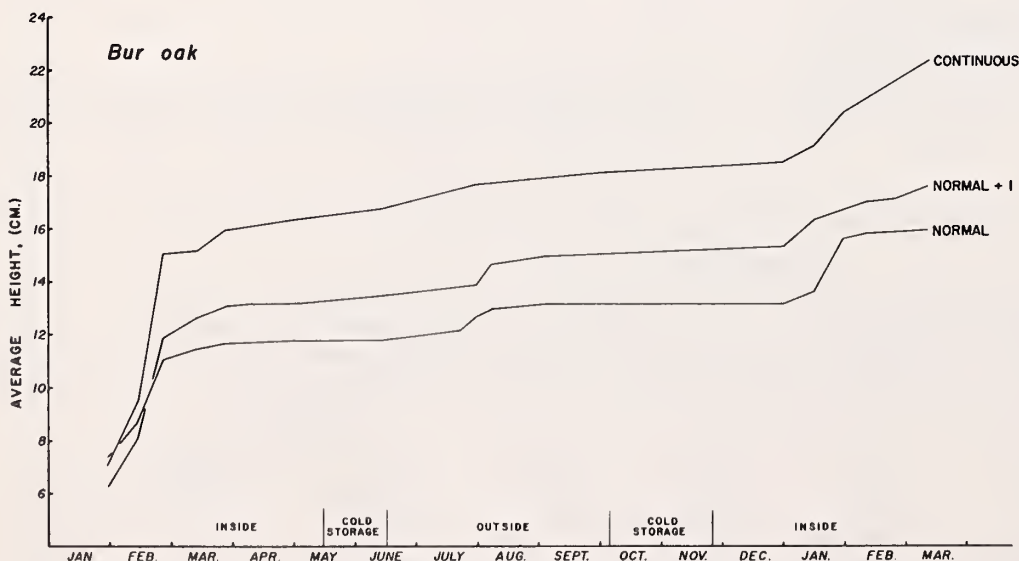


Figure 9.--
Height growth
curves of
bur oak.

EXPERIMENT C

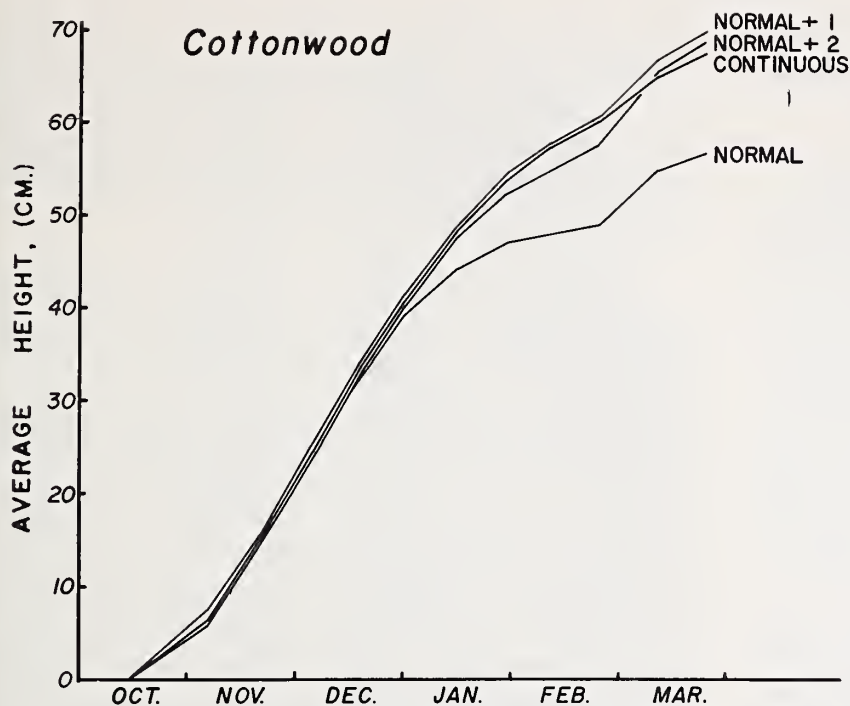


Figure 10.--

Height growth
curves of
lanceleaf cottonwood.

EXPERIMENT E

Seedlings of the two seed trees responded differently. Green weights of progeny from one parent tree were greatest under normal and N + 1 treatments, while progeny of the other parent tree were heaviest under the continuous treatment and lightest under normal. No attempt will be made to explain the different response of progeny of the two seed trees. It is sufficient to note that these data provide strong evidence of the need for using materials of known origin and genetic variability in tree physiology studies.

Summary and Conclusions

All tree species tested grew faster when the normal or natural photoperiod was length-

ened by means of artificial white light. Continuous photoperiods produced the greatest seedling response in most cases. Lesser responses were produced when normal photoperiods were supplemented by several hours of light at either end of the day or within the dark period.

Ponderosa pine, Austrian pine in one experiment, and three species of oak generally flushed more than once during a treatment period under continuous light, and this resulted in taller seedlings than were produced under normal daylength.

Austrian pine in two other experiments responded differently. Under continuous light, the lateral branches grew more than the ter-

Table 10. --Effect of treatments on characteristics of lanceleaf cottonwood in pots,
Experiment E

Characteristic	No. 1 source tree progeny, by treatment				No. 2 source tree progeny, by treatment			
	Normal	N + 1	N + 2	Continuous	Normal	N + 1	N + 2	Continuous
Seedlings (No.)	25	24	26	25	25	24	26	24
Initial height (cm.)	3.6	3.6	3.6	3.6	2.0	2.0	2.0	2.0
20-week height (cm.)	56.4	70.4	66.5	63.6	58.4	69.7	72.1	72.4
Green weight (gm.)	27.9	28.6	25.2	24.5	24.7	27.8	26.8	29.8
Top volume (cc.)	11.5	13.4	12.8	11.0	9.8	13.2	12.9	13.3
Root volume (cc.)	16.5	15.3	12.3	13.5	14.9	14.5	14.0	16.5

minals, and three-needle fascicles were produced. Seedlings grew best under photoperiods longer than normal, but not continuous.

Eastern redcedar responded positively to supplemental light in all experiments, producing taller and heavier seedlings or transplants than under normal daylength. Three species of oaks and lanceleaf cottonwood grew faster than normal under photoperiods lengthened by supplemental white light. Minimum temperatures in September and October slowed the growth of redcedar and oaks, even while under supplemental light. In contrast, ponderosa and Austrian pines continued growth under supplemental light during cooler nights of early fall.

It may be possible to produce ponderosa pine stock of plantable size under lights in 2 instead of 3 years. Eighty-three percent of the 2 + 0 ponderosa pines grown in plots under lights were taller than 4 inches, and most ranged between 6 and 8 inches top height. Although these seedlings were slightly smaller than normally recommended for field planting, 90 percent of them survived when hand planted in the field. On the other hand, 84 percent of the 2 + 0 ponderosa pines grown in check plots were shorter than 4 inches top height, and were too small for field planting.

Results of experiments in which responses of progeny of individual ponderosa and Austrian pines, and cottonwood seed trees were evaluated separately, emphasize the importance of recognizing genetic variation in materials being used for studies of seedling physiology. For example, all five ponderosa pine seed trees grew within a half-mile of each other in the same forest stand. Yet, because of inherent differences, their seedling progenies responded to treatments with significantly different amounts of increased height growth.

Although tall, well-balanced eastern redcedar stock was grown under supplemental light in 2 years, 2 + 0 seedlings produced without light were also large enough for field planting. Consequently, to be useful as a nursery technique, supplemental light would have to grow redcedar seedlings to field planting size in 1 instead of 2 years.

It appears that supplemental lights can be used throughout the growing season, except

during early fall. Lights can be turned on about April 1, but should probably be turned off about September 1 to allow sufficient time for seedlings and transplants to harden off before the first fall frosts. This should prevent cold damage to the tops.

Great improvements have been made in the past 10 years in nursery techniques for growing conifers, especially in the use of soil fumigants, fertilizers, and methods of root pruning; these have produced larger seedlings in fewer years. Supplemental lighting may be useful in the future, however, to enhance seedling growth and quality in nurseries where land space is limited. Further studies would be needed to determine optimum light intensities for various seed origins and seedling stand densities. The effects of light quality should also be studied.

Literature Cited

- Bagley, W. T., and Read, R. A.
1960. Some temperature and photoperiod effects on growth of eastern redcedar seedlings. *Iowa State J. Sci.* 34: 595-602.
- Downs, R. J., and Piringer, A. A., Jr.
1958. Effects of photoperiod and kind of supplemental light on vegetative growth of pines. *Forest Sci.* 4: 185-195.
- Jester, J. R., and Kramer, P. J.
1939. The effect of length of day on the height growth of certain forest tree seedlings. *J. Forest.* 37: 796-803.
- Rudolph, T. D.
1964. Lammas growth and prolepsis in jack pine in the Lake States. *Forest Sci. Monogr.* 6, 68 pp.
- Wareing, P. F.
1956. Photoperiodism in woody plants. *Ann. Rev. Pl. Physiol.* 7: 191-214.
- Watt, R. F.
1961. Artificially extended photoperiod increases size of nursery stock. *Minn. Forest. Note* 104, 2 pp.
- Watt, R. F. and McGregor, Wm. H. D.
1963. Growth of four northern conifers under long and natural photoperiods in Florida and Wisconsin. *Forest Sci.* 9: 115-128.

Read, Ralph A., and Bagley, Walter T.

1967. Response of tree seedlings to extended photoperiods.

U. S. Forest Serv. Res. Paper RM-30, 16 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado, 80521.

Seedlings of Juniperus virginiana, Pinus ponderosa, P. nigra,
Populus X acuminata, Quercus macrocarpa, Q. alba, and Q. rubra
were grown under 14- and 24-hour photoperiods, and 14-hour photo-
periods with one and two light interruptions in the dark period. Most
experiments covered two or three growing periods, in the greenhouse
in winter and outdoors in summer, with very short rest periods.
Seedlings were usually tallest and heaviest under continuous light,
intermediate under the interrupted dark. Long photoperiod stimulated
top growth more than root growth, but did not affect field survival.
Several phenological changes were observed.

Read, Ralph A., and Bagley, Walter T.

1967. Response of tree seedlings to extended photoperiods.

U. S. Forest Serv. Res. Paper RM-30, 16 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado, 80521.

Seedlings of Juniperus virginiana, Pinus ponderosa, P. nigra,
Populus X acuminata, Quercus macrocarpa, Q. alba, and Q. rubra
were grown under 14- and 24-hour photoperiods, and 14-hour photo-
periods with one and two light interruptions in the dark period. Most
experiments covered two or three growing periods, in the greenhouse
in winter and outdoors in summer, with very short rest periods.
Seedlings were usually tallest and heaviest under continuous light,
intermediate under the interrupted dark. Long photoperiod stimulated
top growth more than root growth, but did not affect field survival.
Several phenological changes were observed.

Read, Ralph A., and Bagley, Walter T.

1967. Response of tree seedlings to extended photoperiods.

U. S. Forest Serv. Res. Paper RM-30, 16 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado, 80521.

Seedlings of Juniperus virginiana, Pinus ponderosa, P. nigra,
Populus X acuminata, Quercus macrocarpa, Q. alba, and Q. rubra
were grown under 14- and 24-hour photoperiods, and 14-hour photo-
periods with one and two light interruptions in the dark period. Most
experiments covered two or three growing periods, in the greenhouse
in winter and outdoors in summer, with very short rest periods.
Seedlings were usually tallest and heaviest under continuous light,
intermediate under the interrupted dark. Long photoperiod stimulated
top growth more than root growth, but did not affect field survival.
Several phenological changes were observed.

Read, Ralph A., and Bagley, Walter T.

1967. Response of tree seedlings to extended photoperiods.

U. S. Forest Serv. Res. Paper RM-30, 16 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado, 80521.

Seedlings of Juniperus virginiana, Pinus ponderosa, P. nigra,
Populus X acuminata, Quercus macrocarpa, Q. alba, and Q. rubra
were grown under 14- and 24-hour photoperiods, and 14-hour photo-
periods with one and two light interruptions in the dark period. Most
experiments covered two or three growing periods, in the greenhouse
in winter and outdoors in summer, with very short rest periods.
Seedlings were usually tallest and heaviest under continuous light,
intermediate under the interrupted dark. Long photoperiod stimulated
top growth more than root growth, but did not affect field survival.
Several phenological changes were observed.

